

## Acoustic Monitoring of Dredging-Related Suspended-Sediment Plumes

**PURPOSE:** This technical note presents the results of acoustic monitoring of suspended-sediment plumes during dredging operations. Monitoring was conducted in Mobile Bay, Alabama, during dredging by a hopper dredge and in Boston Harbor, Massachusetts, during dredging by a clamshell dredge. The results show how acoustic monitoring can be used with other instrumentation to provide valuable data characterizing the extent and dynamics of suspended-sediment plumes. Data presented in this technical note provide input for modeling of suspended-sediment plumes, evaluation of dredging methods, and environmental assessments.

**BACKGROUND:** All dredging operations create some form of suspended-sediment plume. To evaluate the environmental effects of the suspended sediment, the location, extent, and physical properties of the resulting plumes need to be determined. Numerical models of dredging-related suspended-sediment plumes (e.g., SSFATE, Johnson and Parchure 1999) can be used to predict the physical properties of the plumes for more locations and for a greater number of environmental conditions than could be practical using field measurements. However, there is a need to monitor a number of test cases to improve and validate the models. A critical parameter in any dredging-related suspended-sediment model is the source term (i.e., the amount of sediment being suspended by the dredge). Different dredging methods produce different amounts, and create different temporal and spatial distributions of suspended sediments. Monitoring conducted in Boston Harbor produced data on the relative amounts of suspension caused by three different types of buckets used by a clamshell dredge.

Interpretation of biological responses to various degrees of exposure to dredging-related suspended-sediment plumes requires quantifying physical properties of the plumes and determining the location of the biological resource relative to the impacted areas. Acoustic methods of making these determinations are useful because they can make measurements rapidly over a wide area. For this reason, they can potentially provide data on which to base the determination of cause and effect in situations where temporal variations are significant, as they are in dredging and dredged-material disposal operations. One of the intended objectives of the monitoring in Mobile Bay was to test the efficacy of combining data from an acoustic Doppler current profiler with data from a fishery hydroacoustics echosounder to examine the interactions between fishes, current flow, and suspended sediment plumes.

**INTRODUCTION:** The presence of suspended sediment can be determined acoustically by sending an acoustic signal through the water and measuring the acoustic energy returned. Sediment particles in suspension in the water column will scatter some of the transmitted acoustic signal, returning a portion of the scattered signal to the instrument. The acoustic energy returned to the instrument is referred to as backscatter. The strength of the backscatter is a function of the size of the sediment particles and the amount of sediment in suspension. Theoretically, it is possible to

calculate the concentration of total suspended solids (TSS) present in the water column if the following conditions are met:

- The particle size distribution of the suspended material is known.
- The salinity and temperature of the water are known.
- The acoustic system has been calibrated.

In practice, when dredging operations are monitored, reliable TSS concentration measurements with known and acceptable accuracy cannot be derived acoustically in routine field operations (see Tubman, Brumley, and Puckette 1994 for a discussion of the theory and Puckette 1998 for a discussion of the problems relating to calculating TSS from the measurements). However, acoustic measurements used with other methods of measuring dredging-related plumes can produce valuable information that, in most cases, could not be obtained if acoustic measurements were not included in the monitoring.

Acoustic measurements of suspended sediment plumes provide the unique capability to produce three-dimensional images of plumes during a relatively short time. Acoustic measurements can rapidly produce images of the relative distribution of suspended-sediment concentrations in the water column. These images can be used to locate the positions of other measurements relative to boundaries of a plume and the spatial distribution of suspended-sediment concentrations. In Mobile, fishery hydroacoustic measurements were made synoptically with the plume-monitoring acoustic measurements. In Boston, additional measurements were optical backscatter and light attenuation, as well as water samples from which TSS values were determined by filtering the samples and weighing the filters. The study areas are shown in Figure 1.

**METHODS:** The acoustic instrument used to monitor the plume during these dredging operations was an RDI five-beam Broad Band Acoustic Doppler Current Profiler (BBADCP). The BBADCP transmits 1,200-kHz acoustic signals through the water and measures the acoustic signals that are returned to the instrument. Four of the five beams point down at a 20-deg angle from the vertical. These four beams measure the water velocity and the velocity of the boat across the bottom. Subtracting the velocity of the boat across the bottom from the water velocity gives the current speed and direction relative to the bottom. The fifth beam points straight down, and its measurements of backscattered acoustic energy are used solely for detecting the presence of suspended sediment in the water column. The BBADCP system used for this monitoring effort has design features developed and implemented in the PLumes Measurement System (PLUMES) specifically for identifying and tracking suspended-sediment plumes from dredging related activities. The development of PLUMES is discussed in Puckette (1998).

The BBADCP records data for both current and fifth-beam backscatter in bins that represent 25-cm-thick slices across each beam, continuously along the beam. They start 50 cm from each beam transducer and produce valid data to near bottom. The data from all five transducers and all bins for each transducer are recorded every 2 sec. The first step in processing the fifth-beam acoustic backscatter data is to correct them for the geometric spreading and viscous attenuation losses of acoustic energy. These losses decrease the amount of backscatter received from each of the 25-cm slices by an amount that increases with distance along each beam. The losses are predictable, and

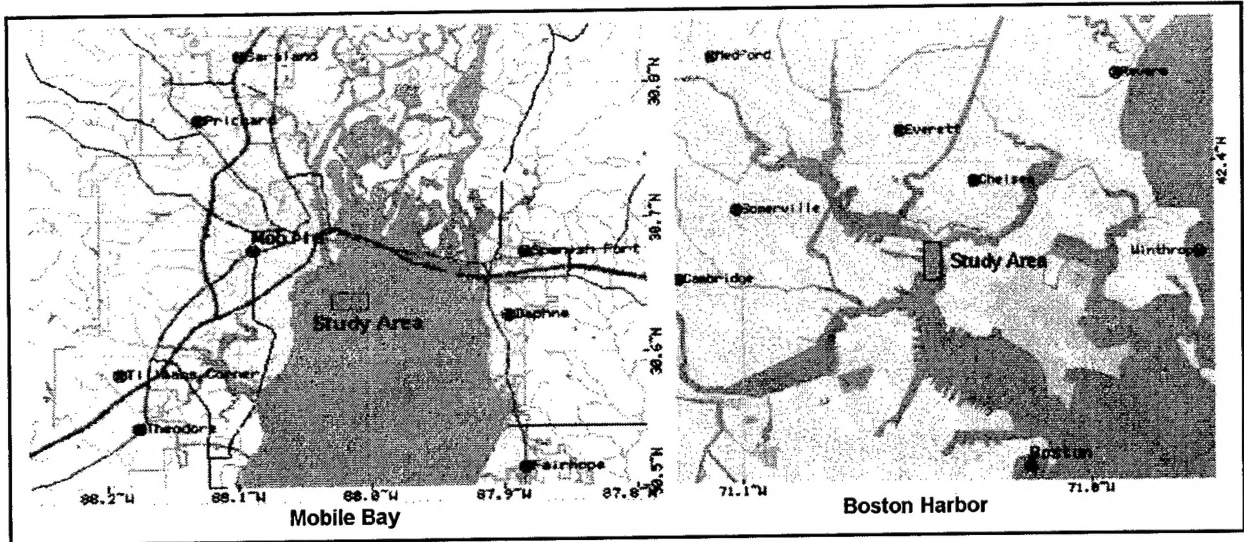


Figure 1. Locations of study areas

occur regardless of the amount of suspended sediment present; consequently their effects on the measurements are removed in the first processing step (Tubman 1995).

One of the most important aspects of applying acoustic technology to monitoring suspended-sediment plumes from dredging operations is to define the ambient acoustic background. It is necessary to determine what conditions exist at the measurement location just before sediment is put into suspension by the operation, and what naturally occurring variations can be expected over the length of time the operation is monitored. Ideally, this is accomplished by making acoustic measurements just before dredging starts, and by calculating statistics from those measurements. In the monitoring reported herein, the naturally occurring variations in ambient acoustic backscatter were determined from measurements made by the BBADCP fifth beam along transects across the study area during times when there was no dredging. In each of the fifth-beam 25-cm bins, the standard deviation of the acoustic backscatter was calculated for all measurements made along these transects. Since the fifth beam points straight down, these values for each bin represent the standard deviation of acoustic backscatter as a function of depth. Just prior to the start of the dredging operations, a transect was made in the area where the plume from the dredging operation was expected to be located. Acoustic backscatter values from this transect (referred to as the background transect) were subtracted from the values obtained during monitoring of the plume, and the results were divided by the standard deviations of the background variations. The result is numbers that represent the observed acoustic backscatter above background (ABAB). The precise manner in which this was done was somewhat different for Boston Harbor than it was for Mobile Bay. In Mobile Bay, the hopper dredge conducted its dredging operation while traversing a confined channel, producing a plume as it proceeded, whereas in Boston Harbor, the clamshell dredge stayed in approximately the same location, in an open area of the harbor, and produced a plume that extended downstream from the dredge. For the Mobile Bay study, the background transect was made across the channel at the midpoint in the length of channel dredged. In Boston Harbor the background transect was run from the dredge, parallel with the current, to a point approximately 600 m downstream from the dredge.

## RESULTS

**Mobile Bay, Alabama.** In January 1999, the U.S. Army Corps of Engineers hopper dredge *Wheeler* dredged a portion of the upper reach of the main navigation channel in Mobile Bay (Figure 1). The dredging operation took approximately 30 min. Figure 2 shows the transects over which measurements were made along the main Mobile Bay navigation channel, and the track the *Wheeler* took while dredging. Transects 1 and 2 occurred before the *Wheeler* began dredging, while Transect 8 occurred after the *Wheeler* had finished dredging. In addition to these transects, four additional transects were run after the *Wheeler* had cleared the area, at approximately the same location as Transect 1. Data from Transect 1 were used when the acoustic background was subtracted from the measurements made while monitoring the plume, and the four transects run after the *Wheeler* left the area were used to determine the background acoustic backscatter variations unrelated to the dredging. Data from Transect 1 were subtracted from measurements made along Transects 2 through 8 by using data from equivalent depths (i.e., from the same bin), and for the same longitude plus or minus 0.0005 min of longitude. This means that each pair of values (i.e., monitoring measurement and background measurement) is from the same position across the channel within approximately 2 m. The results were then divided by the standard deviation for the equivalent depth, determined from the four transects made after the *Wheeler* left the area, resulting

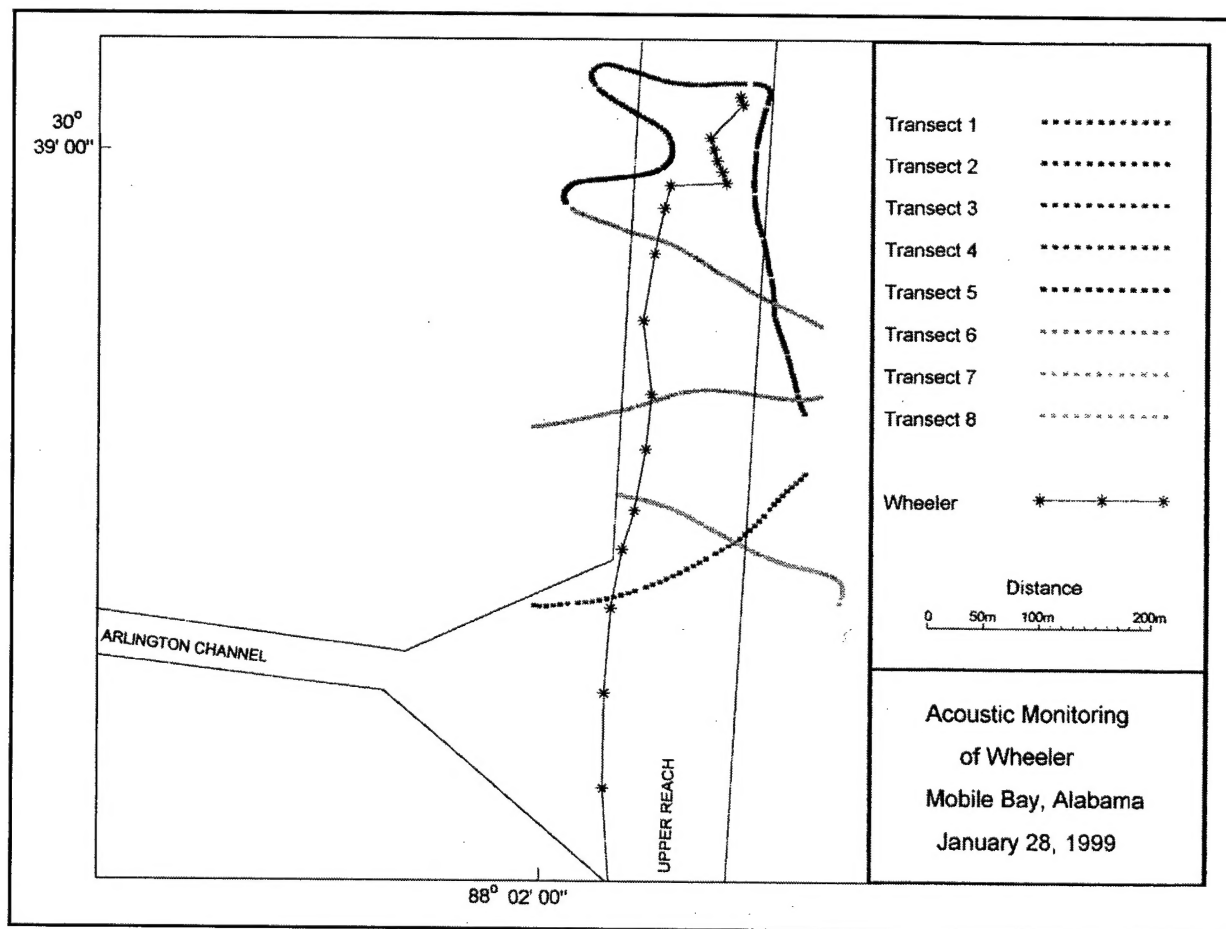


Figure 2. *Wheeler* monitoring transects



in ABAB values. Each ABAB value was assigned a color based on an incremental scale of between 0 and 1, 1 to 1.5, 1.5 to 2, 2 to 2.5, 2.5 to 3, 3 to 3.5, 3.5 to 4, and greater than 4 times the standard deviation above background variations. These are plotted for Transects 2, 6 and 8, in Figures 3, 4, and 5, respectively.

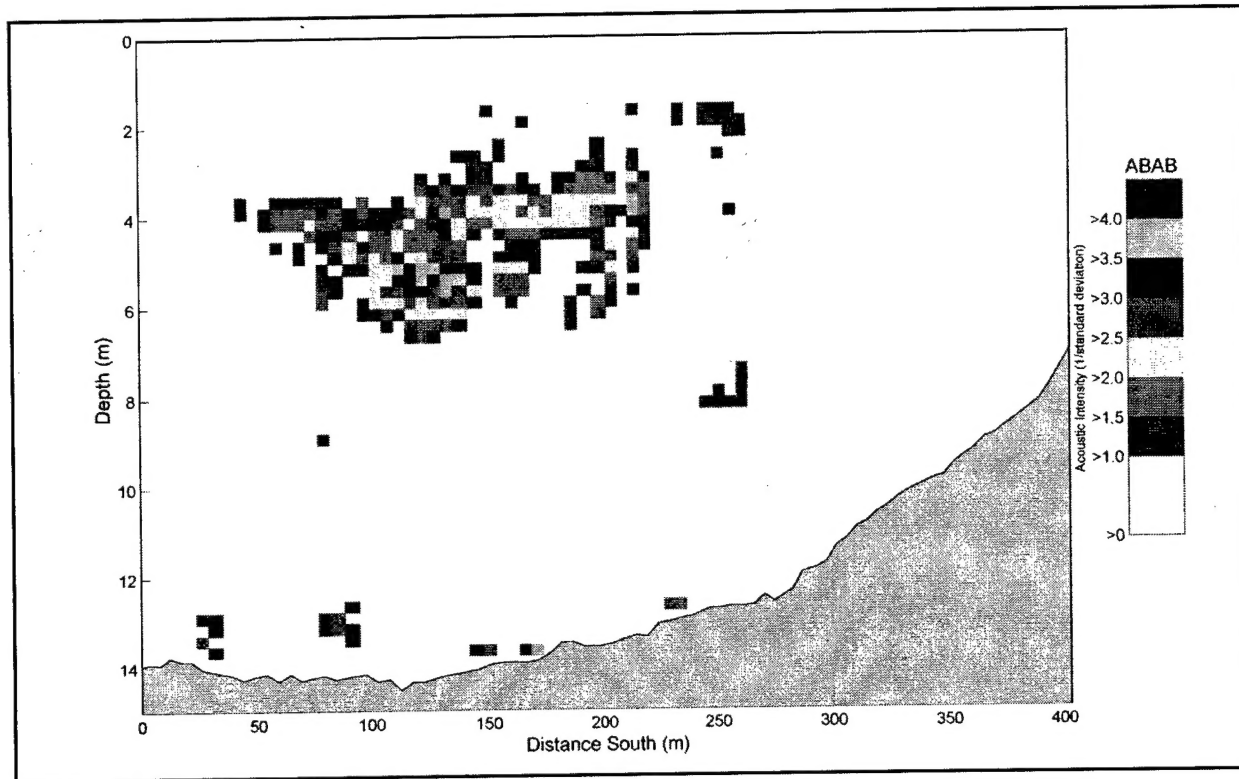


Figure 3. Transect 2, Mobile Bay monitoring

To accomplish the objective of superimposing fishery hydroacoustic data on plume-monitoring acoustic data acquired synoptically, a BioSonics DT 4000 Series digital transducer system was used to make measurements in tandem with the BBADCP. The BioSonics DT is a 200-kHz high-resolution, high-accuracy echo sounder. It is a computer-controlled and -calibrated system used to perform acoustic surveys of aquatic and marine fishery resources. Figure 5 shows targets detected by the system superimposed on ABAB data along Transect 8.

Interpretation of the images presented in Figures 3, 4, and 5 is influenced by the nature of the currents during the monitoring. The monitoring was performed while the survey vessel followed the *Wheeler*, which was dredging while going down the channel toward the Gulf of Mexico. Consequently, the survey vessel needed to catch up to any suspended sediment plumes created by the dredging if the currents were ebbing, but a plume could be expected to move northward into the path of the survey vessel if the currents were flooding. Processing of the BBADCP current data revealed that the flows were ebbing in the upper part of the water column and flooding in the bottom layer. The currents measured across Transect 6, which are typical of those measured along all the transects, are shown in Figure 6. The currents are contoured through points of equal magnitude with positive values being ebb currents and negative values being flood currents. The passage of the *Wheeler* down the channel, and probably its prop wash, have an effect on the current measurements. An asterisk in

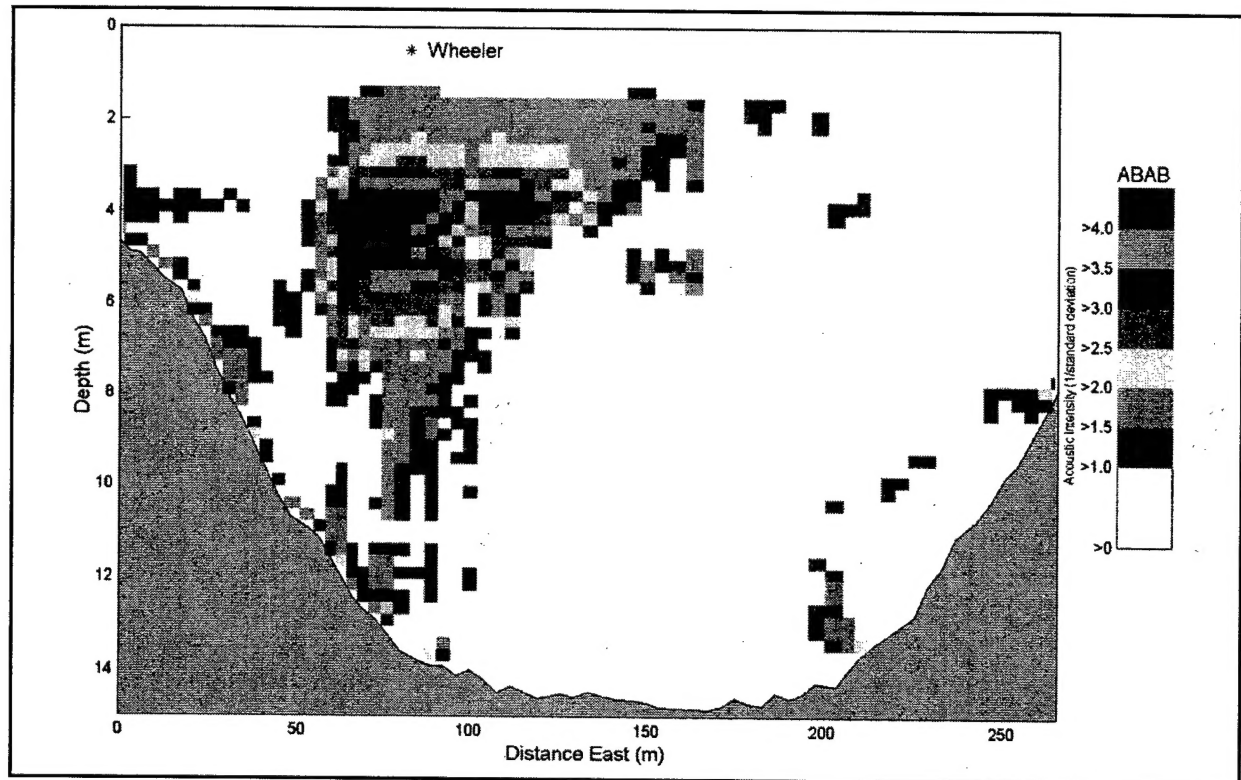


Figure 4. Transect 6, Mobile Bay monitoring

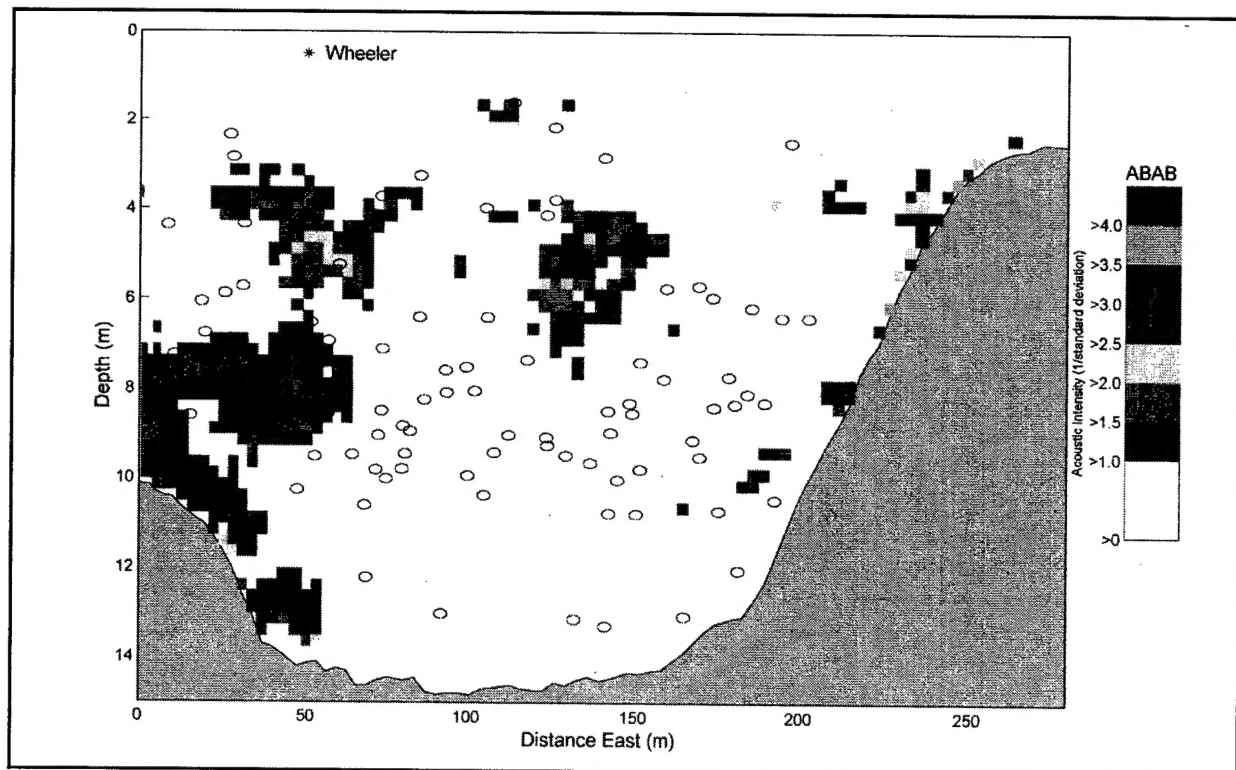


Figure 5. Transect 8, Mobile Bay monitoring

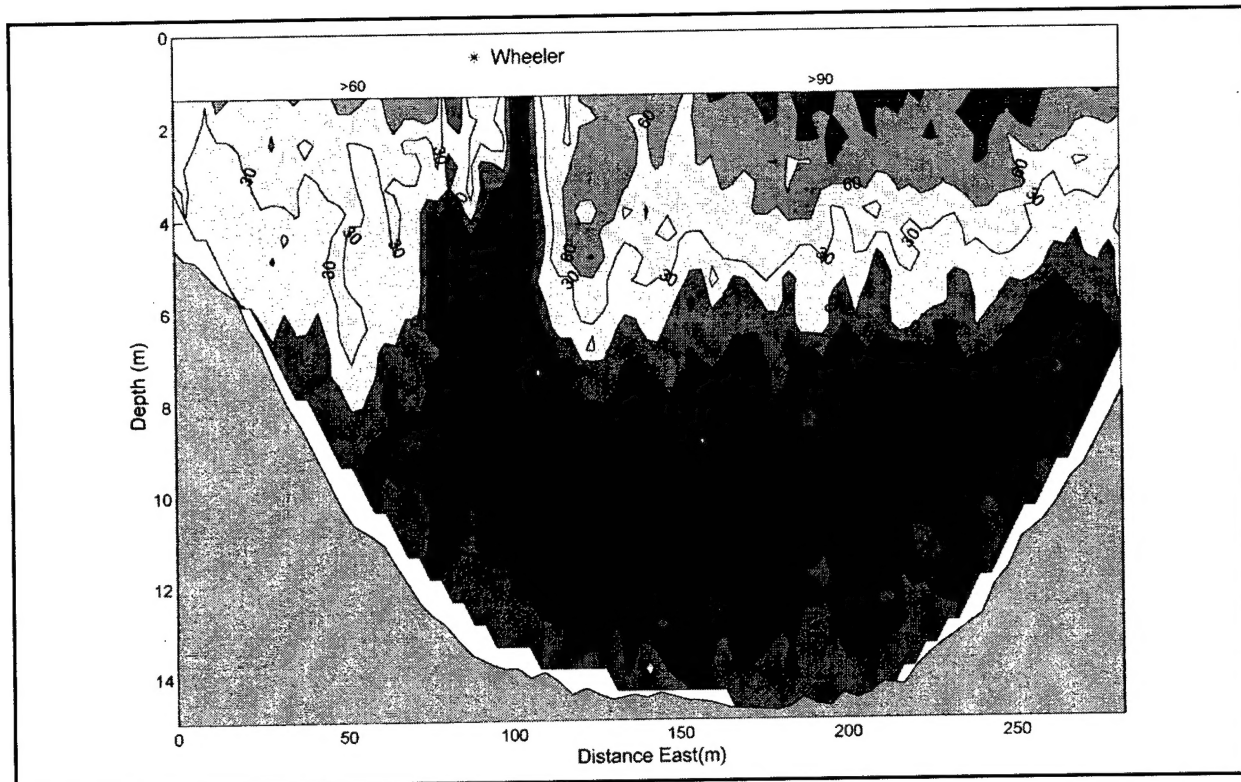


Figure 6. Velocities, cm/sec, at Transect 6 (positive going south, negative going north)

Figures 4 through 6 shows where the *Wheeler* crossed the transect. It can be seen in Figure 6 that the flood currents, which generally extend from the bottom up to a depth of about 6 m, appear to extend up to the surface in the vicinity of the *Wheeler*.

Figure 3 shows Transect 2, which was run just prior to the start of dredging operations. The transect is shown from north to south and is along the eastern side slope of the channel (Figure 2). ABAB is shown at a location where the *Wheeler* had turned to the west to reverse its direction and head down the channel. The ABAB observed on this transect is believed to be a result of air bubbles introduced into the water column from cavitation by the *Wheeler's* screws and rudder.

Figure 4 shows Transect 6, which was run close behind the *Wheeler* while it was dredging. The transect is displayed from west to east. The area of the largest amount of ABAB is at about the 4-m depth. This is approximately the location of the *Wheeler's* screws, and is believed to result from cavitation. Cavitation around the drag arm assembly going from the *Wheeler* to the bottom may be responsible for some of the ABAB shown in that region; however, ABAB near the bottom under the *Wheeler* is probably all due to suspended sediment resulting from the dredging. Bottom-surge currents created by the pressure wave emanating from the passing dredge may have stirred up bottom sediments along the channel side slopes, and may be responsible for the ABAB shown there. Near the surface to the right of the *Wheeler*, ABAB is shown that is believed to be from suspended sediment released at the surface when the *Wheeler* pumped some residual water from its hopper just before it began dredging. The plume from the sediment in that water would be going down the channel with the *Wheeler* as the ebb currents in the surface layer carried it.

Figure 5 (Transect 8) shows an area monitored after the *Wheeler* was well clear of it. The transect is displayed from west to east. There is still some ABAB at approximately the depth of the screws, and there is also some at approximately the same depth to the right of where the *Wheeler* crossed the transect, at about 150 m across. This is believed to be ABAB from a ship screw cavitation. A tug was observed pushing barges down the channel just before the transect was run. A residual plume of suspended sediment in the area dredged is shown by the ABAB in this region on the west side of the channel. The reason for ABAB being observed on the east bank of the channel is unknown.

**Boston Harbor, Massachusetts.** In August 1999, tests of three types of buckets for a clamshell dredge took place in Boston Harbor (Figure 1). Figures 7, 8, and 9 show transects made down the axes of the suspended sediment plumes from clamshell dredging operations. Monitoring took place over 3 days, and on each day a different type bucket was used. On 5 August, a Cable Arm Clamshell™ bucket was monitored. On 6 August, a Great Lakes Closed Environmental Bucket™ was in operation, and the following day a conventional bucket was monitored. Each monitoring operation began just prior to high tide when dredging had been stopped for about an hour to place material dredged earlier into a contained subaqueous disposal pit in the harbor. The pit was well removed from the area being dredged, and it is believed that suspended sediment from the disposal operation did not enter the area being monitored. In this operation, all background monitoring was conducted while the tide was turning and dredging was stopped. When steady ebb flow began, the dredging began again, and the suspended sediment plume from the dredging operation was monitored while one of the disposal scows was filled (maximum capacity of the scows used is 3,058 cu m

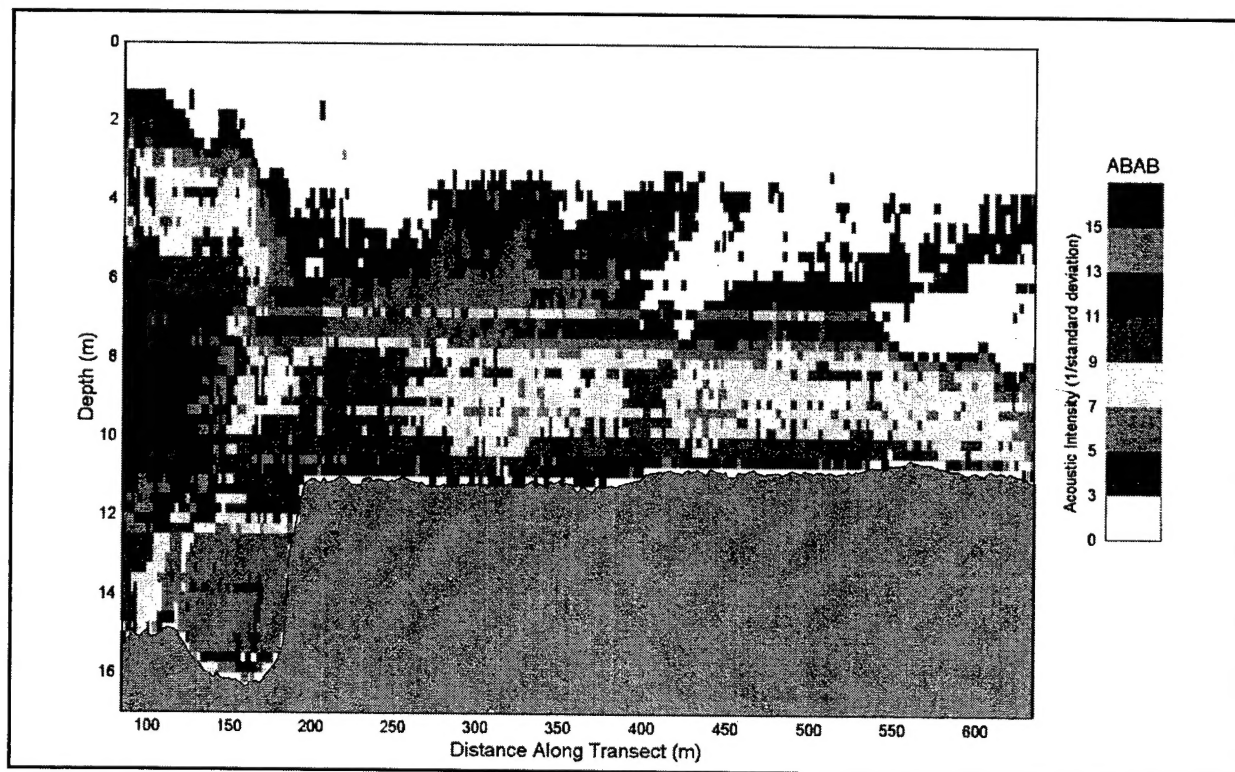


Figure 7. Cable Arm Clamshell, 5 August 1999

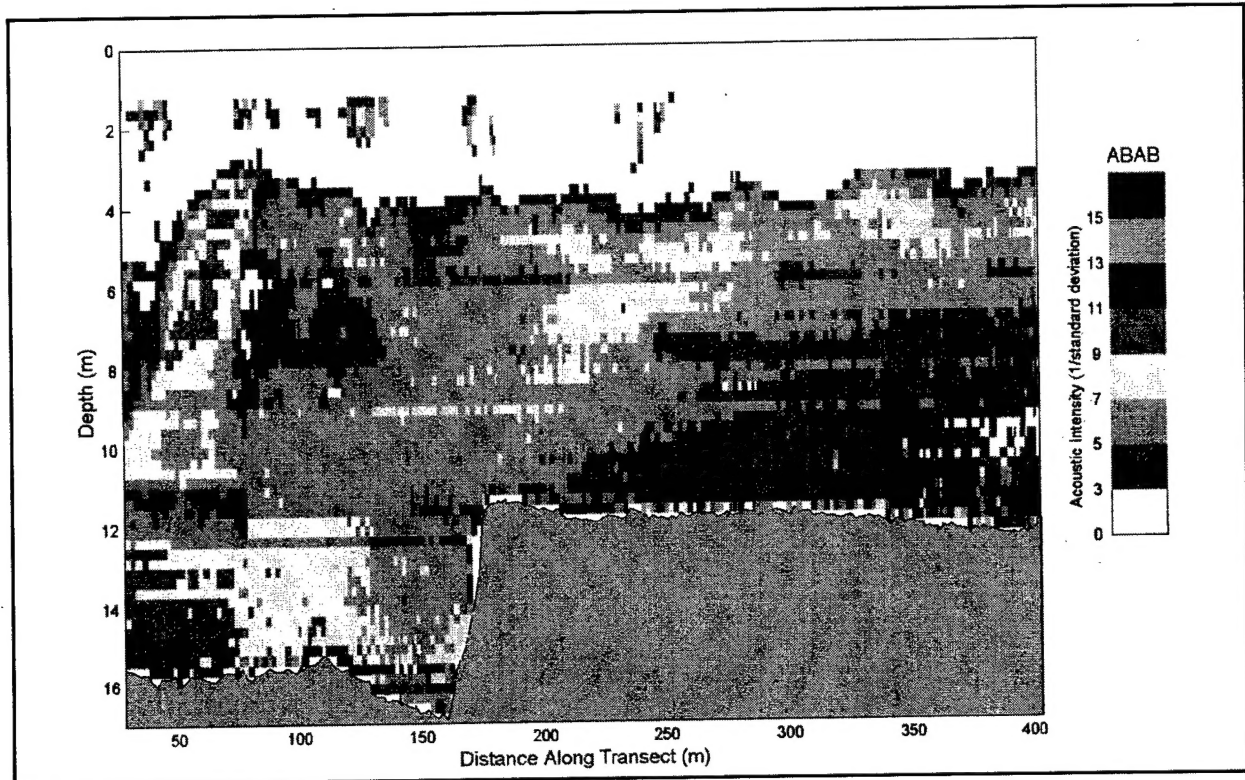


Figure 8. Great Lakes Closed Environmental Bucket, 6 August 1999

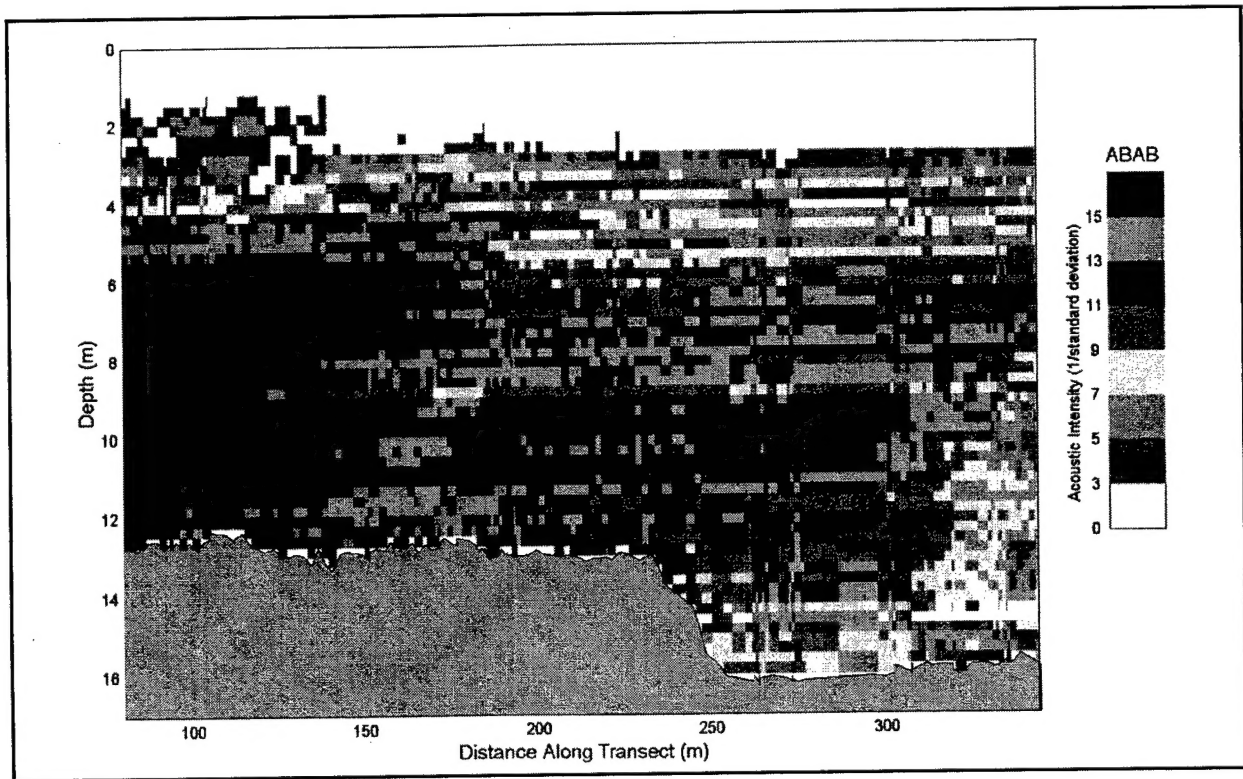


Figure 9. Conventional bucket, 7 August 1999



(4,000 cu yd). The three dredging operations occurred in the same general area, and similar material was dredged in each case. The material dredged was 0.9 to 1.8 m (3 to 6 ft) of sandy silt.

Background monitoring consisted of four to six transects (approximately 190 m long) across the harbor near the dredge, in an area that was upstream of the dredge during ebb flow. Data from these transects were used to calculate the standard deviations of the acoustic backscatter variations for each day. Immediately after these transects were completed and just prior to dredging, the background transect was run from near the dredge downstream to the end of the area monitored. Data from these transects were subtracted from acoustic backscatter measurements made while monitoring the plumes. Due to operational difficulties, the background transect on 5 August could not be run.

On each of the 3 days that a plume was monitored, transects were made perpendicular to the downstream axis of the plume at various distances from the dredge. An example of one of these transects is shown in Figure 10. These transects were run to delineate the cross-stream boundaries of the plume, and extend beyond the edges of the plume into areas where no suspended sediment from the dredging operation was detected. Data from these areas on 5 August were compared with data from the axis transect made before dredging started on 6 August, at equivalent latitudes (the downstream transects along the plume axis are primarily along a constant longitude), and at equivalent depths. It was found that the differences are random, and that 94 percent of the differences are less than two times the standard deviations of the background variations recorded on 6 August. Only 1 percent of the differences are greater than 2.5 times the standard deviations of the background variations. Therefore, the along-axis background transect made on August 6 appears

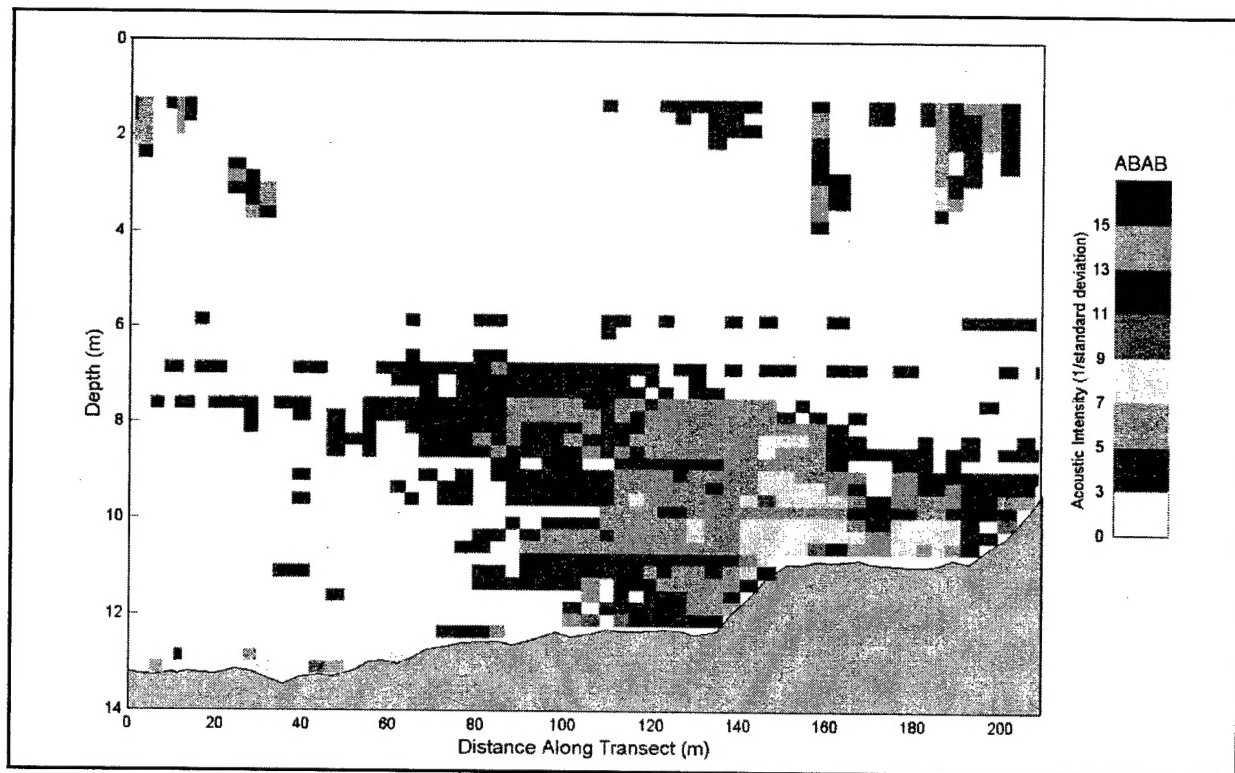


Figure 10. Transect across plume axis, 625 m from dredge, 5 August 1999

to be a reasonable representation of background conditions on 5 August, and it was used to process the data collected on 5 August. In processing the data, background acoustic-backscatter measurements from equivalent depths and distances from the dredge were subtracted from the plume monitoring data, and the results were divided by the standard deviations for equivalent depths, determined on the day of dredging. This resulted in the ABAB values shown in Figures 7 through 10. The ABAB values were assigned a color based on an incremental scale between 0 and 3, 3 to 5, 5 to 7, 7 to 9, 9 to 11, 11 to 13, 13 to 15, and greater than 15 times the standard deviation above background variations. Since the increments are two standard deviations, using the background transect from 6 August to analyze the data from 5 August may randomly move some ABAB values for that day one increment up or down. A very small percentage of the data may move more than one increment. This needs to be taken into account when analyzing the results presented in the figures, but it does not affect the general conclusions drawn from them.

Figure 7 shows the results from a transect run on 5 August, down the axis of the plume, starting near the dredge and running downstream (i.e., north to south). The distances along the horizontal axis are distances from the end of the crane that was used to conduct the dredging. An interesting feature of this transect is that near the dredge, the maximum ABAB values (and therefore the highest concentrations of suspended sediments) are not on the bottom, but approximately 3 m above the bottom. On this day, dredging was conducted with the Cable Arm Clamshell bucket. Examination of the bucket revealed that less than half the seals on the top of the bucket were intact, and it is believed that the higher ABAB values 3 m above the bottom are from sediment being squeezed out the top of the bucket. Figure 8 shows a transect down the axis of the plume on 6 August, when dredging was being conducted with the Great Lakes Closed Environmental Bucket. This figure shows maximum suspended sediment concentrations near the bottom. The relatively high ABAB values at the surface are believed to be from spillage over the side of the scow, resulting from the placement of some sample dredged material on the side deck of the scow for sampling purposes. Figure 9 shows the dredge monitoring results for the conventional bucket. Here maximum concentrations cover more than half the water column and extend all the way to the bottom. In a general qualitative way, the conclusion drawn from these three figures is that for this operation, the Great Lakes Closed Environmental Bucket created less suspended sediment than the Cable Arm Clamshell, and that they both produced less suspended sediment than the conventional bucket. Analysis of other quantitative data (i.e., turbidity and suspended solids measurements) collected during the study is currently under way and will be reported separately.

**CONCLUSIONS:** A procedure for making acoustic measurements and processing the data was shown to make it possible to determine the extent and relative concentrations of suspended sediment plumes from dredging operations. The procedure was successful in an area of high natural turbidity (i.e., Mobile Bay) and in an area of relatively low natural turbidity (i.e., Boston Harbor). The steps in the procedure are as follows:

- Make four to six transects in the dredging area before or after dredging-related suspended sediments are present to determine the naturally occurring variations in acoustic backscatter as a function of depth.
- Just prior to the start of the dredging, make acoustic background measurements along a representative transect that will be used for monitoring the plumes during the dredging.

- Subtract these background values of acoustic backscatter for the equivalent depth and position across the channel (Mobile), or along the plume axes (Boston), from the values measured while monitoring, and divide the differences by the standard deviations of the naturally occurring backscatter for the equivalent depths.

The results of this procedure are ABAB values. When they were plotted for plume cross-sections, they produced qualitative visualizations of the location of the plume and the relative concentrations of suspended sediment.

It was observed in both Mobile and Boston that the most significant difficulty with this procedure was the large ABAB values produced by wakes from ships and boats. The effects of the wakes persisted for a long period of time behind the vessels that produced them, and a method to distinguish ABAB produced by these wakes from that produced by suspended sediment has not been identified. At present, it is necessary to note the wake effects in the field when a vessel passes the area being monitored, and to take the effects into account when interpreting the data.

It was demonstrated in Mobile that measurements from a fisheries hydroacoustic system could be acquired simultaneously with the plume monitoring system and could be plotted on the plume visualizations to show the locations of fish targets relative to the plumes. The BBADCP system used had the additional capability of showing the details of the current flows relative to the plume and fish locations.

The ability to use the acoustic data to visualize the location of the plumes and relative concentrations within the plumes during the monitoring proved to be critical to the success in making other measurements at known locations within the plumes. During the monitoring in Boston, in situ light attenuation and optical backscatter measurements were made simultaneously with the Battelle Ocean Sampling System. Water samples were also taken while the survey vessel was underway. These samples were analyzed to determine TSS. Results from these measurements will provide input to efforts to improve and validate models of dredging-related suspended-sediment plumes. In addition, the information produced by the acoustic system on the spatial extent of the plumes will be valuable input for these modeling efforts. The Boston monitoring also demonstrated the value of acoustic data by itself, by showing qualitatively the relative degrees to which each bucket produced suspended sediment in the water column.

**POINTS OF CONTACT:** For additional information, contact the authors, Mr. M. W. Tubman (601-634-3009, [tubmanm@wes.army.mil](mailto:tubmanm@wes.army.mil)) or Mr. W. D. Corson (601-634-2189, [corsonw@wes.army.mil](mailto:corsonw@wes.army.mil)), or the Program Manager of the Dredging Operations and Environmental Research Program, Dr. Robert M. Engler (601-634-3624, [englerr@wes.army.mil](mailto:englerr@wes.army.mil)). This technical note should be cited as follows:

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